

Express Mail EU943994459US

**APPLICATION
FOR
UNITED STATES LETTERS PATENT**

APPLICANT NAME: Ming-i M. Lin *et al.*

TITLE: MULTILEVEL PARALLEL CRC GENERATION AND
CHECKING CIRCUIT

DOCKET NO.: END920030080US1

INTERNATIONAL BUSINESS MACHINES CORPORATION

MULTILEVEL PARALLEL CRC GENERATION AND CHECKING CIRCUIT

FIELD OF THE INVENTION

The present invention relates to the field of error detection in digital communications; more specifically, it relates to method and circuit for generating and
5 checking a cyclic redundancy check (CRC) for a digital data unit.

BACKGROUND OF THE INVENTION

As the speed of digital communication networks increases and data bandwidths become wider current serial CRC calculation methods and circuits are increasing gating
10 transmission speed because of the time required to generate the CRC or are consuming ever increasing amounts of silicon real estate and power as gate counts increase. Even increasing gate counts not only impacts the physical layout in terms of wireability, but also increases the power consumption of the CRC circuit. Additionally, as data size decreases, the resultant large increase in the size of the CRC increases because of the
15 poor resolution of parallel CRC circuits. Therefore, an improved CRC generation/checking methodology and circuit design is required for high speed, high resolution, and high bandwidth digital communication applications.

SUMMARY OF THE INVENTION

20 A first aspect of the present invention is a CRC generator/checker for generating CRC results, comprising: a set of CRC circuits connected in series, each CRC circuit

END920030080US1

responsive to a different control signal generated by a control logic, each CRC circuit having a seed input adapted to receive a seed, a data input adapted to receive and process a different set of M-bits of a data unit and a result output adapted to generate a result, the result output of a previous CRC circuit connected to the seed input of an immediately

- 5 subsequent CRC circuit, the seed input of a first CRC circuit connected to an output of a remainder register, an input of the remainder register connected to an output of a multiplexer, the result outputs of the multiplicity of CRC circuits connected to different inputs of the multiplexer, the multiplexer responsive to a select signal generated by the control logic.

- 10 A second aspect of the present invention is a CRC generator/checker, comprising:
 - a multiplicity of CRC circuits adapted to process a single-byte of data from a data bus, each CRC circuit having a seed input, a data input adapted to receive a different byte of data from the bus, a control input and a result output; an multiplexer having an output connected to an input of a remainder register, a select input and a multiplicity of inputs,
 - 15 each result output of each the CRC circuit connected to a different input of the multiplexer; each CRC circuit connected in series, the result output of a previous CRC circuit connected to the seed input of an immediately subsequent CRC circuit, the seed input of a first CRC circuit connected to an output of the remainder register; and a control logic having a select output and a multiplicity of control outputs, the select output
- 20 connected to the select input of the multiplexer and the control outputs connected to corresponding control inputs of the CRC circuits.

A third aspect of the present invention is a method of generating and checking a CRC result, comprising: providing a control circuit for generating control signals and a select signal; providing a multiplexer; and providing a set of CRC circuits connected in series, each CRC circuit responsive to a different control signal generated by a control logic, each CRC circuit having a seed input adapted to receive a seed, a data input adapted to receive and process a different set of M-bits of a data unit and a result output adapted to generate a result, the result output of a previous CRC circuit connected to the seed input of an immediately subsequent CRC circuit, the seed input of a first CRC circuit connected to an output of a remainder register, an input of the remainder register connected to an output of the multiplexer, the result outputs of the multiplicity of CRC circuits connected to different inputs of the multiplexer, the multiplexer responsive to a select signal generated by the control logic.

BRIEF DESCRIPTION OF DRAWINGS

The features of the invention are set forth in the appended claims. The invention itself, however, will be best understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a schematic diagram of a CRC generator/checker circuit according to a first embodiment of the present invention;

FIGs. 2A through 2C are diagrams illustrating the operation of the CRC generator/checker circuit of FIG. 1;

END920030080US1

FIG. 3 is a schematic diagram of a CRC generator/checker circuit according to a second embodiment of the present invention;

FIG. 4 is a schematic diagram of a specific CRC generator/checker circuit according to a third embodiment of the present invention; and

5 FIG. 5 is a schematic diagram of a general CRC generator/checker circuit according to a fourth embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

For the purposes of the present invention, the term data unit is defined as a set of
10 related data bits or data bytes. The size of a data unit can be variable and the number of bits or bytes in a data unit does not matter. Examples of data units include but are not limited to data packets, asynchronous transfer mode (ATM) cells and frames. The notation [| FUNC|] is read as the largest integer not exceeding the absolute value of FUNC. The notation 2^X should be read as 2^X and the notation $2^{(X-Y)}$ should be read
15 as 2^{X-Y} . Since one byte is equal to 8-bits, a circuit processing M-bits of data at one time is a 1-byte circuit when M is equal to eight.

FIG. 1 is a schematic diagram of a CRC generator/checker circuit 100 according to a first embodiment of the present invention. In FIG. 1, CRC generator/checker circuit 100 includes a multiplicity of one-byte (8-bit) CRC circuits 105, a control logic 110, a
20 result multiplexer 115 and a K-bit CRC remainder registers 117. Each CRC circuit 105 has a seed input, a data input, a control input and a K-bit result output. K is dependent on the particular CRC parameter used to generate the CRC check bits that are appended to
END920030080US1

the data unit before transmission. Each data input of each CRC circuit **105** is adapted to receive a different byte of data from a W-byte wide data bus **120**. (CRC circuits **105** may be considered 1-byte CRC circuits) Therefore, there are W CRC circuits **105** in CRC generator/checker circuit **100**. CRC circuits **105** can be custom designed based on 5 application and technology and CRC being implemented. While the internal structure of CRC circuits **105** can vary, the inputs, output and function of CRC circuits is well known and many examples exist.

CRC circuits **105** are connected in series, the result output of a previous CRC circuit connected to the seed input of an immediately subsequent CRC circuit. Each 10 result output of each CRC circuit **105** is also connected to a different input of result multiplexer **115**. The output of result multiplexer **115** is connected to the input of remainder register **117**. The result outputs of each CRC circuit **105** form the CRC RESULT of CRC generator/checker **100**. Multiplexer **115** is responsive to a SEL signal generated by control logic **110**. The SEL signal chooses the result of the CRC circuit 15 processing the last byte of the current data. The output of remainder register **117** is connected to the seed input of the first CRC circuit **105** (the one receiving byte 1). Control logic **110** generates one bit control signals CNTRL1 through CNTRLW based on delimiters in the data stream on data bus **120**. Each control signal CNTRL1 through 20 CNTRLW is connected to a corresponding control input of CRC circuits **105**. Control signals determine if the incoming seed is to be used by a particular CRC circuit **105** or if

the seed is to be reset internally by the CRC circuit itself. Thus, circuit **100** can handle a data unit of any number of bytes.

In one example, a logical 1 control signal on a particular CRC circuit **105** will disconnect the seed input from of the particular CRC circuit from the result output of a 5 previous CRC circuit **105** and cause the particular CRC to generate a reset K-bit seed internally, where K is dependent on the CRC parameter by CRC generator/checker **100**.

In one example, the internally generated seed is all logical 0s. In one example W is 32. The operation of CRC generator/checker **100** is illustrated in FIGs. 2A through 2C and described *infra*.

10 CRC generator/checker circuit **100** processes a data unit as received via data bus
120. When used as a CRC generator, CRC RESULT of CRC generator/checker circuit
100 is concatenated to the end of the data unit and the thus modified data unit transmitted.
When used as a CRC checker, the received data unit is run through CRC
generator/checker circuit **100** and if CRC RESULT is all zeros or a fixed pattern of ones
15 and zeros, then the data unit is considered to have been received free of transmission
induced errors.

FIGs. 2A through 2C are diagrams illustrating the operation of CRC
generator/checker circuit **100** of FIG. 1. Note that the data transfer to the CRC circuits
illustrated in FIGs. 2A and 2B occur at the same clock cycle and the data transfer to the
20 CRC circuits illustrated in FIG. 2C occur during the next clock cycle. In FIGs. 2A
through 2C, CRC generator/checker circuit **100** is illustrated symbolically as a chain of 32

CRC circuits **105A1** through **105A32**. In FIG. 2A, CRC generator **100** is initialized, CRC circuit **105A1** is seeded with all zeros or a fixed pattern of ones and zeros, a 5-byte data unit A is loaded into CRC **105** circuits **105A1** through **105A5**, and the output result of CRC circuit **105A5** is CRC RESULT A. Data unit A with CRC RESULT A
5 concatenated may then be transmitted or checked.

In FIG. 2B, CRC circuit **105A6** is seeded with all zeros or a fixed pattern of ones and zeros, the first 27 bytes of a 32-byte data unit B are loaded into CRC circuits **105A6** through **105A32**, and the output result of CRC circuit **105A32** is CRC RESULT B1.

In FIG. 2C, the last 32 bytes of 32-byte data unit B are loaded into CRC circuits
10 **105A1** through **105A5**, the seed of **105A1** is the output result of CRC **105A32** and the output result of CRC circuit **105A5** is CRC RESULT B2 and CRC circuit **105A6** is seeded with all zeros or fixed pattern of ones and zeros in anticipation of the next data unit. Data unit B with CRC RESULT B2 concatenated may then be transmitted or checked.

15 FIG. 3 is a schematic diagram of a CRC generator/checker circuit **125** according to a second embodiment of the present invention. In FIG. 1, CRC generator/checker circuit **125** includes a multiplicity of M-bit CRC circuits **130**, a control logic **135**, a result multiplexer **140** and a remainder register **142**. Each CRC circuit **130** has a seed input, a data input, a control input and a K-bit result output. K is CRC parameter dependent.
20 Each data input of each CRC circuit **130** is adapted to receive a different set of M-bits of data from a C by N bit wide data bus **145**. Therefore, there are C CRC circuits in CRC

generator/checker circuit **125**. CRC circuits **130** can be custom designed based on application and technology. While the internal structure of CRC circuits **1310** can vary, the inputs, output and function of CRC circuits is well known and many examples exist.

- CRC circuits **130** are connected in series, the result output of a previous CRC
- 5 circuit connected to the seed input of an immediately subsequent CRC circuit. Each result output of each CRC circuit **130** is also connected to a different input of result multiplexer **140**. Multiplexer **140** is responsive to a SEL signal generated by control logic **135**. The output of result multiplexer **140** is connected to the seed input of the first CRC circuit **130** (the one receiving bits 1 to M). The SEL signal chooses the result of the
- 10 CRC circuit processing the last bits of the current data. The result outputs of each CRC circuit **130** form the CRC RESULT of CRC generator/checker **125**. CRC generator/checker **125** processes data units in C by M-bit groups. Control logic **135** generates one bit control signals CNTRL1 through CNTRLC based on the number of bits (up to a maximum of C x M) of the current data unit on data bus **145**. Each control signal
- 15 CNTRL1 through CNTRLC, which are dependent on the delimiters of current data units in the data stream on data bus **145**, is connected to a corresponding control input of CRC circuits **130**.

- In one example, a logical 1 control signal on a particular CRC circuit **130** will disconnect the seed input from of the particular CRC circuit from the result output of a
- 20 previous CRC circuit **130** and cause the particular CRC to generate a reset K-bit seed. In one example, the seed is all logical 0s. In one example, N is 32 and C is 4 and K is CRC

parameter dependent. Thus, in this example, CRC circuits **130** are 4-byte CRC circuits, that is, capable of processing 4-bytes of data at a time. The operation of CRC generator/checker **125** is similar to that of CRC generator/checker **100** of FIG. 1 and described *supra*.

5 A limitation of CRC generator/checker circuit **100** of FIG. 1 is the number of 1-byte concatenations that can be done in one clock cycle may be limited by the circuit design, wiring delays and technology of the integrated circuit incorporating the CRC generator/checker. The third and fourth embodiments of the present invention overcome this limitation. The third embodiment of the present invention uses a limitation of the
10 number L of 1-byte CRC concatenations that can be done in one clock cycle. L is a function of the speed limitation of a given integrated circuit technology. In one example $L=10$. The fourth embodiment of the present invention uses the general limitation of L .

FIG. 4 is a schematic diagram of a specific CRC generator/checker circuit **150** according to a third embodiment of the present invention. In FIG. 4, a 32-byte data bus is
15 assumed. CRC generator/checker circuit **150**, includes a first level result generator **155** which includes 32, 1-byte (8-bit) CRC circuits **160**, and a set of multiplexers **165** connected to corresponding byte 11 through byte 32 CRC circuits **160**. CRC generator/checker circuit **150** further includes a second level result generator **180** including a multiplexer **185** and a 16-byte CRC circuit **190**, two third level result
20 generators **195A** and **195B** including respective multiplexers **200A** and **200B** and corresponding 8-byte CRC circuits **205A** and **205B**, a fourth level result generator **210**,

END920030080US1

including a multiplexer **215** and a 4-byte CRC generator **220**, a control logic **225**, a result multiplexer **230** and a CRC remainder register **232**. There are two third level result generators **195A** and **195B** in order to handle the case where two data units greater than 10 bytes but less than 16 bytes occur in succession. The number of 8-byte, CRC

5 generators (Q) is determined by the equation (1).

$$Q = \lceil W/(L+1) \rceil \quad (1)$$

where:

Q = the largest integer not exceeding $|W/(L+1)|$;

W = the number of 1-byte CRC circuits in the first level result generator and the

10 width of the data bus; and

L = the number of 1-byte CRC concatenations that can be done by 1-byte CRC circuits in one clock cycle.

Substituting W = 32 and L= 10 gives Q=2.

Each CRC circuit **160**, **190**, **205A**, **225B** and **220** has a seed input, a data input, a
15 control input and a K-bit result output. Control logic **225** is adapted to receive data from a 32-byte wide data bus (not shown). Control logic **225** generates control signals for each CRC circuit **160**, **190**, **205A**, **205B**, and **220** select signals for each multiplexer **165**, **185**, **200A**, **200B**, **215** and **230** and directs specific data bytes of a current data unit to the appropriate data input of each CRC circuit **160**, **190**, **205A**, **205B** and **220** based on the
20 number of bytes of data in the current data unit.

It should be understood, due to the cyclic nature of CRC generator/checker **150** that references in the description of the structure of the CRC generator/checker to a CRC circuit connected to a designated byte (byte .1, byte 2,etc.) means that a wiring path to control logic **225** from the data input bearing that designation of the CRC circuit exists,

5 but the actual presence of data on that wire and the specific data byte of a specific data unit on that wire is conditional on the number of data bytes in the current data unit and previous data units and is controlled by control logic **225**. The direction of particular data bytes of a data unit to particular CRC circuits is described *infra*.

CRC circuits **160** are connected in series, the result output of a previous CRC

10 circuit **160** connected to the seed input of an immediately subsequent CRC circuit **160** though for the 10 byte through 31 byte CRC circuits **160** the input is through a multiplexer **165**. Each data input of each CRC circuit **160** is adapted to receive a single data byte as directed by control logic **225**. The data input of the first CRC circuit **160** in the series is connected to byte 1, the data input of the second CRC circuit **160** is

15 connected to byte 2 so on until the data input of the 32nd CRC circuit **160** is connected to byte 32. The result of the first CRC circuit **160** in the series is R1, the result of the second CRC circuit **160** is R2 so on until the result of the 32nd CRC circuit **160** is R32. The seed inputs of 10 byte through 31 byte CRC circuits **160** are connected to the output of corresponding multiplexer **165**. The inputs of multiplexers **165** are connected to the

20 result outputs of corresponding immediately previous CRC circuits **160** and to the outputs CRC circuits **190, 205A, 205B** and **220**, which are results RL2, RL3A, RL3B, RL4

respectively. Each result output of each CRC circuit **160** (R1 through R32) with RL2, RL3A, RL3B and RL4 are connected to a different input of result multiplexer **230**. The output of result multiplexer **230** is connected to the input of remainder register **232**. The output of remainder register **232** is connected to inputs of multiplexers **185**, **200A**, **200B** and **215**, and the seed input of byte 1 CRC **160**. Results R1 through R32, RL2, RL3A, RL3B and RL4 are the CRC RESULT of CRC generator/checker **150**.

First level result generator **155** functions similarly as CRC generator/checker **100** of FIG. 1 except for the addition of multiplexers **165**, which account for cycles through CRC circuits **190**, **205A**, **205B** and **220**.

10 The data input of CRC circuit **190** is adapted to receive 16 bytes of data as directed by control logic **225**. The seed input of CRC circuit **190** is the output of multiplexer **185**. The inputs of multiplexer **185** are the output of remainder register **232** and R1 to R32.

The data input of CRC circuit **205A** is adapted to receive 8 bytes of data as
15 directed by control logic **225**. The seed input of CRC circuit **205A** is the output of multiplexer **200A**. The inputs of multiplexer **200A** are the output of remainder register **232**, RL2 and R1 to R32.

The data input of CRC circuit **205B** is adapted to receive 8 bytes of data as
20 directed by control logic **225**. The seed input of CRC circuit **205B** is the output of multiplexer **200B**. The inputs of multiplexer **200B** are CRC the output of remainder register **232**, RL2, RL3A and R1 to R32.

The data input of CRC circuit **220** is adapted to receive 4 bytes of data as directed by control logic **225**. The seed input of CRC circuit **220** is the output of multiplexer **215**. The inputs of multiplexer **215** are CRC RESULT, RL4, RL3A, RL3B and R1 to R32.

While multiplexers **185**, **200A**, **200B** and **215** are illustrated and described as
5 separate from corresponding CRC circuits **190**, **205A**, **205B** and **220**, the multiplexers
may be incorporated into the corresponding CRC circuits. Similarly, multiplexers **165**
may be incorporated into the 11th byte and 32nd byte CRC circuits **160**.

When CRC generator/checker **150** receives data units, control logic **220**
determines the data unit sizes and data unit boundaries (the separation between adjacent
10 data units). For CRC circuits **160**, the byte location of unit boundaries determines
whether the seed input of a particular CRC circuit **160** remains connected to the output
result of the previous CRC circuit **160** or an all 0 seed is generated within the CRC circuit
160. For CRC circuits **190**, **205A**, **205B** and **220**, the data unit boundary determines
whether the seed is a result from multiplexer **185**, **200A**, **200B** or **210** respectively or all
15 zeros. Note, the seed need not be all zeros, but may be any combination of ones and
zeros depending upon the design of the CRC circuits. Control logic **225** then directs the
various bytes of the data unit to specific CRC circuits according to the rules in TABLE 1.
It should be remembered that Table 1 is for L=10 and if a data unit is more than 32 bytes,
it is processed as groups of 32 bytes plus one group of MOD(number of bytes in the data
20 unit). Also, the specific 1-byte CRC circuits **160** (if any) used, depends upon the
previous byte loading of the 1-byte data CRC circuits **160**.

TABLE 1

Bytes In Data Unit	CRC Circuits	
5	1 to 10 Bytes 11 Bytes 12 Bytes 13 Bytes 14 Bytes	Use 1 to 10 1-byte CRC circuits Use 1 8-byte and 3 1-byte CRC circuits Use 1 8-byte and 4 1-byte CRC circuits Use 1 8-byte, 1 4-byte and 1 1-byte CRC circuits Use 1 8-byte, 1 4-byte and 2 1-byte CRC circuits
10	15 Bytes 16 Bytes 17 Bytes 18 Bytes 19 Bytes	Use 1 8-byte, 1 4-byte and 3 1-byte CRC circuits Use 1 8-byte, 1 4-byte and 4 1-byte CRC circuits Use 1 16-byte and 1 1-byte CRC circuits Use 1 16-byte and 2 1-byte CRC circuits Use 1 16-byte and 3 1-byte CRC circuits
15	20 Bytes 21 Bytes 22 Bytes 23 Bytes 24 Bytes	Use 1 16-byte and 4 1-byte CRC circuits Use 1 16-byte, 1 4-byte and 1 1-byte CRC circuits Use 1 16-byte, 1 4-byte and 2 1-byte CRC circuits Use 1 16-byte, 1 4-byte and 3 1-byte CRC circuits Use 1 16-byte, 1 4-byte and 4 1-byte CRC circuits
20	25 Bytes 26 Bytes 27 Bytes 28 Bytes 29 bytes	Use 1 16-byte, 1 8-byte and 1 1-byte CRC circuits Use 1 16-byte, 1 8-byte and 2 1-byte CRC circuits Use 1 16-byte, 1 8-byte and 3 1-byte CRC circuits Use 1 16-byte, 1 8-byte and 4 1-byte CRC circuits Use 1 16-byte, 1 8-byte, 1 4-byte and 1 1-byte CRC circuits
25	30 bytes 31bytes 32 bytes	Use 1 16-byte, 1 8-byte, 1 4-byte and 2 1-byte CRC circuits Use 1 16-byte, 1 8-byte, 1 4-byte and 3 1-byte CRC circuits Use 1 16-byte, 1 8-byte, 1 4-byte and 4 1-byte CRC circuits or use 1 16-byte and 2 8-byte CRC circuits

30

Taking the example of an initial loading of successive data units of sizes 11-bytes, 11 bytes and 10 bytes, control logic 225 would allocate CRC circuits as follows:

- (1) the first 11-byte data unit uses three 1-byte CRC circuits 160 with the byte 1 CRC circuit **160** seed all zeros, the byte 2 CRC circuit **160** seed R1 and the byte 3 CRC circuit

160 seed R2 and the first 8-byte CRC circuit 205A with seed R3 and the result of the
CRC calculation is RL3A; and

(2) the second 11-byte data unit uses three 1-byte CRC circuits 160 with the byte 4 CRC
circuit 160 seed all zeros, the byte 5 CRC 160 seed R4, the byte 6 CRC circuit 160 seed

5 R5 and the second 8-byte CRC circuit 205B with seed R6 and the result of the CRC
calculation is RL3B; and

(3) the 10-byte data units uses ten 1-byte CRC circuits byte 7 CRC circuit 160 through
byte 16 CRC circuit 160, the seed of byte 7 CRC circuit 160 is all zeros. Others are
seeded with the immediately previous 1-byte CRC circuit 160 result.

10 Logic circuit 225 is designed such that it allocates data units such that a worst-case
CRC calculation requiring all four levels of processing (32 bytes data using one 16-byte
CRC plus one 8-byte CRC plus one 4-byte CRC plus 4 1-byte CRC, can be
completed in one clock cycle.

FIG. 5 is a schematic diagram of a general CRC generator/checker circuit 250
15 according to a fourth embodiment of the present invention. In FIG. 5, a W-byte data bus
is assumed. CRC generator/checker circuit 250 includes a first level result generator 255
which includes W of 1-byte (8-bit) CRC circuits 260, (W-L) multiplexers 265 connected
to corresponding byte L+1 through byte W CRC circuits 260. L is the number of 1-byte
CRC concatenations that can be done in one clock cycle as described *supra*. With this
20 method, high resolution, CRC calculation on any size data unit can be accomplished

while avoiding customer design for each very high speed network requiring cyclic redundancy checking.

CRC generator/checker circuit **250** further includes a $2^{(N-1)}$ (second level) result generator **280** including a multiplexer **285** and a $2^{(N-1)}$ -byte CRC circuit **290**, a $2^{(N-2)}$ 5 (third level) result generator **295** including, a multiplexer **300** and a $2^{(N-2)}$ -byte CRC circuit **305**, and additional 2^Z result generators, in the series with Z is integer from (N-3) to X+1 if $(N-3) \geq X+1$. If $(N-3) < X+1$, then there's no 2^Z result generator in between. N is defined by $2^N > W \geq 2^{(N-1)}$, X is defined by $(2^X) \leq L$ and $(2^{(X+1)}) > L$.

CRC generator/checker **250** further includes Q sets of (2^X) result generators **310**, 10 each including a multiplexer **315** and (2^X) -byte CRC generator **320**. $Q = [|W/(L+1)|]$ as defined *supra* in equation (1). There are Q multiplexers **315** and (2^X) result generators **310**.

CRC generator/checker **250** further includes a last level 2^Y result generator **325** including a multiplexer **330** and a (2^Y) -byte CRC circuit **335**. There are also additional 15 2^P result generators in the series with P is integer from Y-1, to X-1 if $X > Y$. If $X \leq Y$, there is no 2^P result generator in between.

Each CRC circuit **260**, **290**, **305**, **320** and **335** has a seed input, a data input, a control input and a K-bit result output where K is CRC parameter dependent. The output of result multiplexer **345** is connected to the input of a remainder register **347**. The 20 output of remainder register **347** is connected to one input of each multiplexer **280**, **295**, **310** and **325** and the seed input of byte-1 CRC circuit **260**. Control logic **340** generates

control signals for each CRC circuit **260**, **290**, **305**, **320** and **335** select signals for each multiplexer **265**, **285**, **300**, **315**, **330** and **345** and directs specific data bytes of a current data units to the appropriate data input of each CRC circuit **260**, **290**, **305**, **320** and **335** based on the number of bytes of data in the current data unit.

- 5 CRC circuits **260** are connected in series, the result output of a previous CRC circuit **260** connected to the seed input of an immediately subsequent CRC circuit **260** from byte 1 to byte L CRC circuits **260** though for byte (L+1) to byte W CRC circuits **260** the input is through a multiplexer. Each data input of each CRC circuit **260** is adapted to receive a single data byte as directed by control logic **340**. The data input of the first
- 10 CRC circuit **260** in the series is connected to byte 1, the data input of the second CRC circuit **260** is connected to byte 2 so on until the data input of the Wth CRC circuit **260** is connected to byte W. The result of the first CRC circuit **260** in the series is R1, the result of the second CRC circuit **260** is R2 so on until the result of the Wth CRC circuit **260** is RW. The seed input of the byte L through byte W CRC circuits **260** are connected to the
- 15 output of respective multiplexer **265**. One input of each multiplexer **265** is connected to the result output of the immediately previous CRC circuit **260** and to the outputs of $(2^{(N-1)})$ CRC circuit **290**, $(2^{(N-2)})$ CRC circuit **305**, ..., (2^X) CRC circuit **320**, ..., (2^Y) CRC circuit **335** and all intervening CRC circuits between CRC circuit **305** and **320** and between CRC circuit **320** and **335** which are respectively, results RES $2^{(N-1)}$,
- 20 RES $2^{(N-2)}$ through Q of RES 2^X and through RES 2^Y .

Each result output of each CRC circuit **260** (R1 through RW) is connected to a different input of result multiplexer **345**. First level result generator functions similarly as CRC generator/checker **100** of FIG. 1 except for the addition of multiplexers **265**, which allows the results of CRC circuits **290**, **305**, **320** and **335** to be used as seeds.

5 The data input of CRC circuit **290** is adapted to receive $2^{(N-1)}$ bytes of data as directed by control logic **340**. The seed input of CRC circuit **290** is the output of multiplexer **285**. The inputs of multiplexer **285** are the output of remainder register **347** and R1 to RW.

The data input of CRC circuit **305** is adapted to receive $2^{(N-2)}$ bytes of data as
10 directed by control logic **340**. The seed input of CRC circuit **305** is the output of multiplexer **300**. The inputs of multiplexer **300** are the output of remainder register **347**,
RES $2^{(N-1)}$ and R1 to RW.

The data input of CRC circuits **320** are adapted to receive 2^X bytes of data as
directed by control logic **340**. The inputs of multiplexers **315** are the output of remainder
15 register **347**, RES $2^{(N-1)}$ through RES $2^{(X+1)}$, any RES 2^X in lower level (not shown
in FIG. 5) and R1 to RW.

The data input of CRC circuit **335** is adapted to receive 2^Y bytes of data as
directed by control logic **340**. The seed inputs of CRC circuit **335** are the output of
multiplexer **330**. The inputs of multiplexer **330** are the output of remainder register **347**,
20 RES $2^{(N-1)}$ through RES $2^{(Y+1)}$ and R1 to RW.

The output of CRC generator/checker **250** are R1 though R32, RES $2^{(N-1)}$, $2^{(N-2)}$, ..., Q modules of 2^X , ..., 2^Y .

While multiplexers **285**, **300**, **315** and **330** are illustrated and described as separate from corresponding CRC circuits **290**, **305**, **320** and **335**, the multiplexers may be
5 incorporated into the corresponding CRC circuits. Similarly, multiplexers **265** may be incorporated into the (L+1) byte through W byte CRC circuits **260**.

When CRC generator/checker **250** receives a data unit, control logic **340** determines the data unit size and data unit boundary (the separation between adjacent data units). For CRC circuits **260**, the data unit boundary determines whether seed inputs of a
10 particular CRC circuit **260** remains connected to the output result of the previous CRC circuit **260** or an all 0 seed is generated within the CRC circuit **260**. For CRC circuits **290**, **305**, **320** and **335**, the data unit boundary determines the seed is a result from multiplexer **285**, **300**, **315** or **330** respectively or all zeros. Note, the seed need not be all zeros, but all ones or any combination of ones and zeros depending upon the design of the
15 CRC circuits. Control logic **340** then directs the various bytes of the data unit to specific CRC circuits according to the rules in a manner similar to that described for CRC generator/checker **150** (see FIG. 3) in TABLE 1 *supra*. If a data unit is more than W-bytes, it is processed as groups of W bytes plus one group of as many bytes that remain after processing groups of W bytes.

20 The timing criteria for CRC generator **250** is defined by (1) each multi-byte CRC circuit **280**, **295**, only one multi-byte CRC circuit **310** (though there are Q modules) and

END920030080US1

multi-byte CRC circuit **335** and all intervening multi-byte CRC circuits processing different numbers of bytes of data selected from the series of powers of two bytes in the range $2^{(N-1)}$ to 2^Y where $2^{(N-1)}$ is equal to the number of CRC circuits **260** and Y is less than (N-1) and where Y is chosen such the number of concatenated multi-byte CRC

- 5 calculations performed plus ($W-[2^{(N-1)}+2^{(N-2)}+\dots+2^X+\dots+2^Y]$) concatenated 1-byte CRC circuit **260** calculations can be performed in a single clock cycle and (2) the number Q of identical multi-byte CRC circuits able to process (2^X)-bytes of data is defined by the largest integer not exceeding $|W/(L+1)|$ where W, the data bus width, is also the number of CRC circuits **260** and where X is defined by $(2^X) \leq L$ and
- 10 $2^{(X+1)} > L$ where L is a maximum number of 1-byte concatenated CRC calculations that can be done by CRC circuits **160** in a single clock cycle. Further, logic circuit **340** is designed such that it allocates data units such that a worst-case CRC calculation requiring all levels of processing can be completed in one clock cycle.

Returning to FIG. 4, the timing criteria described *supra* when applied to CRC

- 15 generator/checker **150** is met with W=32, L=10, N=5, X=3, Y=2 and Q=2.

Thus, the present invention provides an improved CRC generation/checking methodology and circuit design is required for high speed, high resolution and high bandwidth digital communication applications.

The description of the embodiments of the present invention is given above for

- 20 the understanding of the present invention. It will be understood that the invention is not limited to the particular embodiments described herein, but is capable of various

modifications, rearrangements and substitutions as will now become apparent to those skilled in the art without departing from the scope of the invention. Therefore it is intended that the following claims cover all such modifications and changes as fall within the true spirit and scope of the invention.

5

END920030080US1

21